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A RAT CHAMBER AND ELECTRODE PROCEDURE FOR AVOIDANCE CONDITIONING[1]

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A method was developed for studying the reactions of rats to aversive shock. The distinctive features were the design of the chamber and a method of restraint that allowed the use of surface electrodes to deliver the shock. Advantages of this method were: (1) accurate specification of the shock actually received by the rat; (2) elimination of all unauthorized escape or avoidance reactions; (3) elimination of the shock scramblers and floor grids required with foot-shock; and, (4) rapid acquisition of performance under various avoidance procedures and various frequencies of shock delivery.

The extensive use of rats for shock-escape and shock-avoidance studies has been accompanied by concern for improved methods of shock delivery (see Dinsmoor, 1966). Ideally, the shock received should be specifiable as to intensity, duration, and bodily locus and should not be modified by any unauthorized escape or avoidance reactions by the rat. The most common method is to deliver shock through the electrified rods of the floor of the experimental chamber.

One problem in using electrified rods is that the feces of the animal can cause an electrical short circuit across the rods. Skinner and Campbell (1947) described a method of reducing this problem by mechanically dislodging the feces; Dinsmoor (1958) described a floor-rod arrangement that permitted sufficient spacing between rods to prevent the electrical short circuit.

A second problem is that the rat can stand only on rods of the same electrical polarity and thereby avoid shock. A widely adopted solution was devised initially by Skinner and Campbell (1947), who developed a "scrambling" circuit that repeatedly changed the polarity of each grid. As Sloan (1964) has pointed out, some scrambling circuits may still permit the rat to reduce shock partially by learning that a given pair of floor rods is of the same polarity more often than others. Similarly, duration of current flow across a given pair of rods is greatly influenced by the rapidity of polarity alternation of the circuit, as seen from Bolles' (1966) comparison of three commercially available units. Consequently, several types of circuits have been recently proposed for their ability to achieve more rapid, reliable, and uniform polarity alternation (Hoffman and Fleshler, 1962; Markowitz and Saslow, 1964; Campbell and Jerison, 1966; Parks and Sterritt, 1964; Wyckoff and Page, 1954; Snapper, 1966; Owen and Kellermeier, 1966).

The third major problem with electrified floor grids is that the intensity of current flow at a given moment depends on the degree of physical contact between the freely moving rat and the rods (Campbell and Teghtsoonian, 1958; Bolles, 1966). Although Dinsmoor (1958) partly solved this problem by using large rods to achieve a greater area of contact with the rat, the degree of contact with any floor surface must depend on the posture and amount of movement by the rat. Another attempt has been to develop circuits that will approximate constant current flow in spite of variations in the resistance of the rat (Dinsmoor, 1961), usually by using a very high voltage source and placing a large resistor in series with the rat. These circuits are, of course, ineffective when the rat jumps completely off the floor rods.

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One solution to the problem of guaranteeing shock delivery is to use electrodes that are implanted or fastened to the surface of the skin. Shock-avoidance conditioning has been achieved by internal electrodes with the pigeon (Azrin, 1959; Azrin, Hake, Holz, and Hutchinson, 1965), and surface electrodes with the pigeon (Hoffman and Fleshler, 1959) and monkey (Weiss and Laties, 1962, 1963; Hake and Azrin, 1963; Azrin, Holz, Hake, and Ayllon, 1963; Morse and Kelleher, 1966; Azrin, Hutchinson, and Hake, 1967). Our own efforts to use subdermal electrodes with rats have been thwarted by (1) the frequent physiological rejection of the electrodes within eight weeks after implantation, and, (2) the interference with the operant avoidance responses by a "freezing" immobility of the rat in reaction to the internal shock. de Toledo and Black (1965) devised a method of implanting chronic electrodes in the rat and have used it effectively in the conditioned-suppression procedure of Estes and Skinner (1941), but its effectiveness for shock avoidance is still undetermined.

Surface electrodes have been used with rats, for example, for recording physiological reactions (Ferraro, Silver, and Snapper, 1965) and licking responses (DeBold, Miller, and Jensen, 1965), as well as for delivering shock as a punisher (Bijou, 1942) and as the unconditioned stimuli in the conditioned suppression procedure (Hall, Clayton, and Mark, 1966). Since the rat will remove a surface electrode that delivers aversive shock, DeBold *et al.* (1965) and Bijou (1942) physically restrained the rat to prevent it from removing the electrodes; but, as Bijou found for one of his restraining devices, "Holder A", excessive restraint interfered with operant responding. Several other types of restraint have been devised (Ebel, 1966; DeBold *et al.*, 1965) all of which involved total bodily restraint that allowed relatively little opportunity for engaging in free operant responding. Yet, extensive restraint seems to be necessary because of the rat's success in compressing its body and escaping from partial restraint. In spite of the attractiveness of electrodes for assuring shock stimulation, no method has yet been reported for developing and maintaining shock-avoidance behavior of rats (see discussion of this same problem by Dinsmoor, 1966).

The present report describes a method of conditioning shock-avoidance responding of rats by means of surface electrodes. The distinctive features of the method are: (1) attaching electrodes to the tail of the rat, (2) restraining only the tail and leaving the body unrestrained, (3) use of a tail stock to prevent the rat from reaching and removing the electrodes, (4) a method of restraining the tail that minimized injury to it from struggling, and (5) a chamber design that reduced the force which could be exerted against the tail restraint.

Subjects

Thirty-three male Holtzman Sprague Dawley rats, 90 to 130 days of age at the time of the first experimental session, were used.

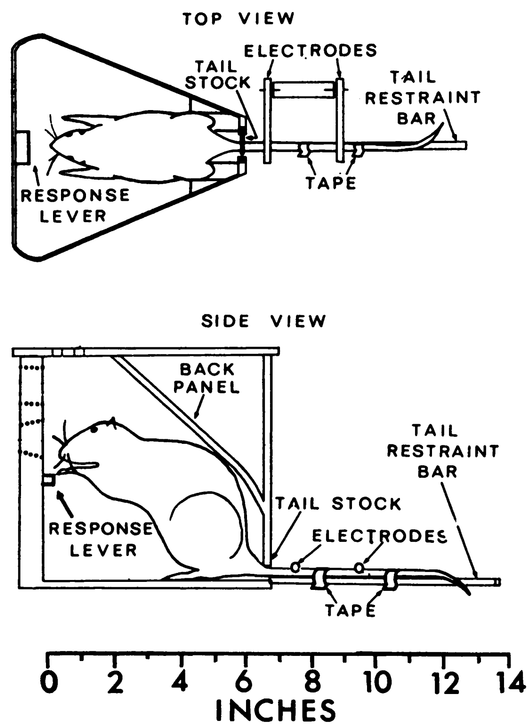

Fig. 1. Scale drawing of the experimental chamber for studying shock avoidance of rats.

Apparatus

Figure 1 is a schematic of the experimental chamber designed to give the rats considerable freedom of movement while being sufficiently restrained to permit the use of tail electrodes. The interior of the chamber was 7-in. long, 2-in. wide at the rear, enlarging to 7¼ in. toward the front and 7¾-in. high at the front, decreasing to 2-in. high at the tail stock.

The chamber was constructed entirely of smooth plastic (Plexiglas) molded into the desired shape by warming and bending the sheets. The smooth plastic surface prevented self-injury to the rat from contact with rough surfaces when it struggled to free itself and also prevented the animal from exerting much force against the tape that restrained its tail. If the animal could obtain traction because of irregularities in the floor surface, the degree of restraint on its tail had to be prohibitively great. Great care was necessary therefore to eliminate irregularities and especially any openings at the juncture of walls and floors. The "back panel" (side view of Fig. 1), consisting of a curved sheet of plastic, also minimized the force that the rat could exert against its tail: the curvature of the panel prevented the rat from arching its body completely around and pulling itself free by pressing against the back wall (tail stock). Similarly, the funnel shape of the side walls (top view of Fig. 1) served the same function. The floor area adjacent to the tail stock contained an opening 1¼-in. long which extended the width of the chamber and allowed all feces and urine to drop into a pan below (top view of Fig. 1). Metal rods ³⁄₃₂-in. diameter and ¾-in. apart extended the length of the opening and prevented the animal from exploring into the opening while still allowing some support for the hind legs. As a rule, the rat positioned its hind legs forward of the hole. For this reason, the hole was made longer than needed for simple feces disposal, since the greater length seemed to prevent the rat from remaining at the extreme rear of the chamber. Similarly, the wide spacing between the rods seemed to prevent the rat from standing on them.

Two large holes 1⅛ in. in diameter were located in the upper part of the front wall; several smaller holes were in the ceiling of the chamber. These holes allowed air to circulate and encouraged exploratory movements toward the holes in the vicinity of the response lever. The walls were sufficiently thick around the holes (about 1 in.) to prevent the rat from using its teeth as an anchor point around the outer edge of the hole and thereby pulling its tail free.

The rat was placed in the chamber by lifting the hinged roof, removing the tail stock and rear wall as a unit, and fastening the rat to the tail restraining rod. To assure that the rat was in the same position in the apparatus, and that the electrodes were in the same position on the tail, ink marks on the tail were used as a placement guide. About ½ in. of the tail was forward of the rear wall but this distance could be changed slightly to accommodate different size rats. If much less distance were allowed, the rat had difficulty moving about; if too much distance were allowed, the rat spent considerable time exploring the rear of the chamber and engaging in apparent escape movements.

In the initial stages of developing this method, the tail was fastened directly to the restraining rod with a single strip of adhesive tape. This proved unsatisfactory because of frequent vascular occlusion and because of injury to the tail when the tape was removed after each session. To avoid these problems, two strips of tape were used at each of the points where the tail was fastened to the restraining rod (Fig. 1). One strip was wrapped loosely around the tail only; a second strip fairly loosely encircled both the rod and the first strip. This allowed the tape to be attached more loosely, since the inner strip of tape provided adhesive contact with the entire circumference of the tail. Consequently, when the rat pulled forward, the force was transmitted to the entire circumference of the tail through the inner tape, rather than to one segment of it. The result was little or no damage to the tail even during periods of active struggling by the rat. At the end of a session, only the outer strip of tape, which attached to the rod, was removed. Some rats allowed the inner tape to remain undamaged on their tail for several days; others removed it in their living cages but without injury.

Shock was delivered to the tail by two external electrodes that rested lightly on the tail with a force of about 15 g. The electrodes were constructed of ¼-in. diameter brass rods notched to conform to the curvature of the tail at the point of contact. EKG Sol electrode paste was applied to the tail before each session. The shock source was an Applegate Model 228 constant current stimulator. Shock was delivered for 100 msec at an intensity of 3 ma.

The response mechanism was a Lehigh Valley rat lever (Model #1352) mounted 2¾ in. from the floor; it was 1⅛-in. wide, ⅜-in.

thick and extended ½ in. from the wall. A force of 15 g was needed to depress the lever sufficiently to activate a switch, which defined the response. A click sound accompanied each lever depression.

An overhead lamp provided illumination during each experimental session. A buzzer outside of the chamber was used to provide a discriminative stimulus. A small fan directed air at the holes in the front and top of the chamber. The chamber was located within a larger sound-attenuating enclosure, one wall of which contained a large window that permitted observation of the rat. All programming and recording were performed by electrical circuits located in an adjoining room.

Procedure

Four different types of avoidance procedure were scheduled, each of which has been used for previous studies of avoidance. The objective was to determine whether these four types of avoidance procedure would also be effective with the present apparatus. Figure 2 is a schematic of the four procedures:

(1) The discrete trials avoidance procedure scheduled a single shock at regular intervals preceded by the buzzer sound (conditioned stimulus) that terminated with the shock. If a lever-press was emitted during the buzzer sound, it terminated the sound and avoided the shock. A lever-press before the buzzer had no effect. This type of procedure had been used by Bechterev (1932), Brogden, Lipman, and Culler (1938), and more recently by Azrin *et al.* (Exp. IIC, 1967).

(2) The discrete trials escape-avoidance procedure as used by Mowrer (1940) was similar to the discrete trials avoidance procedure in that responses during the buzzer terminated it, and responses in the absence of the buzzer had no effect. The procedure differed from discrete trials avoidance in that the buzzer continued to sound and shocks occurred at regular intervals during the buzzer until a response was emitted. A variation of this procedure has been used in which the shocks occur at irregular intervals during the conditioned stimulus (Dinsmoor, 1962; Azrin, Holz, and Hake, 1962; Azrin, Holz, Hake, and Ayllon, 1963).

(3) In the non-discriminated continuous avoidance procedure which was used initially by Sidman (1953), no conditioned stimulus was present. Shocks were delivered at regular intervals of time; when the rat responded, the shocks were postponed. Unlike the two discrete trials procedures, all responses were effective.

(4) The discriminated continuous avoidance procedure, which has been used by Sidman (1955), Sidman and Boren (1957), and Ulrich, Holz, and Azrin (1964), was the same as the discrete-trials escape-avoidance procedure except that responses in the absence of the buzzer postponed it. In none of the procedures could the brief shock delivery (100 msec) be terminated.

Since the objective of this study was to determine in a general manner whether the present method would generate avoidance responding, rather than to compare the different procedures, a wide range of values was employed for the duration of the conditioned stimulus and the interval between a response and the shock. The values were different for each rat but constant for a given rat. For all rats, the interval between successive shocks was constant at 2 sec during both of the continuous avoidance procedures and in the escape period of the discrete-trials escape-avoidance procedure. The interval by which the buzzer sound preceded a shock (CS-UCS interval) varied from 3 sec to 30 sec for different animals in all procedures, except, of course, in the non-discriminated continuous avoidance procedure in which no buzzer was used. The in-

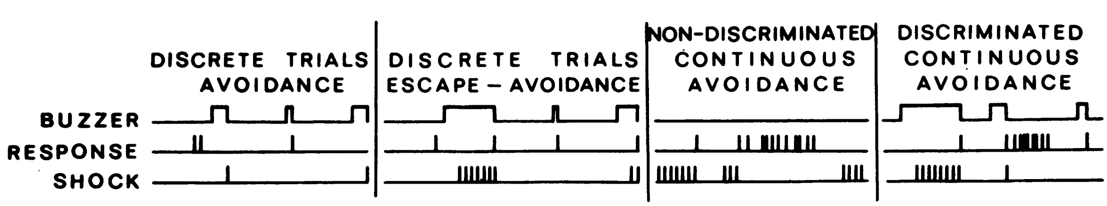

Fig. 2. Schematic of the four different avoidance procedures used, illustrating how the shock delivery and the buzzer sound were affected by the lever-press responses. The response pattern depicted is not intended to characterize actual performance but to illustrate the manner in which responses can affect the buzzer sound and the shock delivery.

terval between a response and a shock (R-UCS interval) varied from 10 sec to 60 sec.

Twenty rats were given a single session. The other 13 rats were given up to 24 sessions. Each session was 3.5 to 8 hr and was given daily to ascertain the effects of extended restraint.

In order to determine whether the lever presses were being maintained by the shock schedules or by some extraneous factor such as buzzer termination, 12 of the rats that had been conditioned for at least three sessions were then given at least three more sessions in which the shock generator was disconnected, but all other stimulus changes occurred. Reconditioning was evaluated by providing several more sessions with the shock reinstated.

RESULTS

Before the first shock was delivered, none of the rats struggled against the tail restraint. During initial conditioning, each delivery of shock produced a backward lunge toward the base of the tail where the rat often remained facing to the rear for a few seconds after shock. As a consequence, shock delivery never directly "elicited" a lever press since the response lever was located in front of the rat. This backward lunge upon shock delivery characterized the behavior of all rats during the initial session; it was greatly reduced or absent for all rats after the lever-press had been conditioned.

Several rats that had received many shocks during the first session became damp with perspiration. After the first two sessions, when these rats were receiving fewer shocks, no physical signs of debility were apparent, even for the rats given an 8-hr session daily.

Figure 3 shows the first 2.5 hr of avoidance conditioning of four different rats, each of which was exposed to a different avoidance procedure. The four illustrative rats were selected such that the interval between a response and a shock (R-UCS interval) was 30 sec for each of the procedures, that value being about midrange of those used. A high frequency of shocks was received at the start of conditioning, decreasing to a lower level by the end of the 2.5-hr period. Several responses were emitted within the first 5 min and often before the first shock delivery by all but one of the 33 rats used, indicating that the chamber design itself produced an operant level on which the conditioning procedure could act without shaping. One rat had a near-zero level of responses (four in the 2.5-hr period). The records in Fig. 3 are otherwise characteristic of all rats in that avoidance was acquired within one session. The major exception was the non-discriminated continuous avoidance schedule at values of the R-UCS interval less than 30 sec. All five rats used with a R-UCS interval less than 30 sec adopted an "escape" pattern in which responses occurred almost exclusively in a burst after a shock delivery. The four rats used with R-UCS interval of 30 sec or more were avoiding almost all shocks by the end of the first session. In all of the procedures in which the buzzer signaled the shock, the responses occurred primarily at the onset of the buzzer sound, thereby producing the uniformly spaced response pattern (see Fig. 3) at the end of the session.

By the end of the second session, all rats were avoiding over 95% of the shocks with the exception of the five rats noted above that had shocks scheduled within 20 sec or less of the avoiding response. Gross observation revealed that these rats were relatively motionless (freezing behavior) after each post-shock burst of responses. These rats showed little reduction of the number of shocks received during additional sessions, although all of the other rats showed a progressive decrease.

When the shocks were discontinued for 13 of the rats (avoidance extinction), the response rate decreased to less than 10% of the conditioned rate on the first day of extinction for six rats and by the third day for three more rats. For the other four rats, the response rate decreased to less than one response per minute by the third day of extinction, a level which was still 10 to 25% of the conditioned response rate, since the long intertrial interval (40 to 50 sec) for the four rats produced a relatively low avoidance rate. On the first day of reconditioning, the rate of response of all 13 rats increased to a value between 80 and 110% of the rate before extinction.

DISCUSSION

The present method appeared to generate avoidance behavior about as rapidly as other methods that have used grid shock. No exact

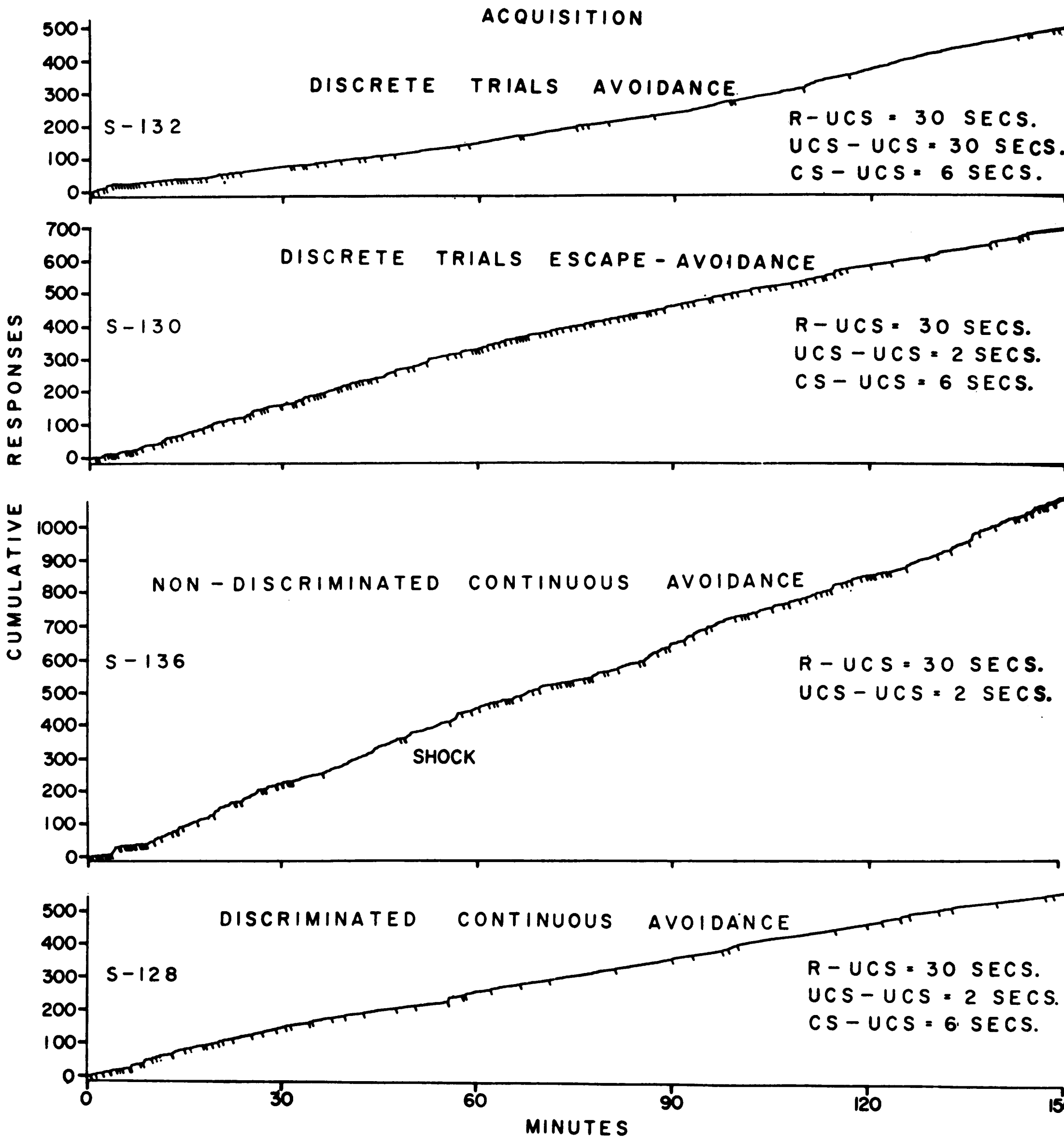

Fig. 3. Cumulative response records of the acquisition of lever-press avoidance of shock by four rats, each conditioned by a different type of avoidance procedure. The short downward movement of the recording pen indicates a shock delivery. The solid bar-like section on the two middle records resulted from shocks delivered in rapid succession. Each of the four designated procedures was conducted at the schedule values listed to the right of the curve. CS-UCS designates the interval between the onset of the conditioned stimulus and the delivery of the unconditioned stimulus (shock). R-UCS designates the interval between a response and a shock, whereas UCS-UCS is the interval between successive shocks when no responses intervened.

comparison is possible between this tail-electrode procedure and foot-shock procedures, however, because of the many other incidental differences between them. The rapid decrease of responses during extinction and increase of responses during reconditioning revealed that responding was under control of the shock schedule and did not reflect simply a high operant level, nor any inherent aversiveness of the conditioned stimulus. The avoidance responding was maintained throughout the shock schedule for as long as 8 hr per day over several weeks, indicating no debilitating effects of the restraint.

The major disadvantage for avoidance acquisition was the inefficiency of the avoidance responding during the non-discriminative continuous avoidance schedule at short R-UCS intervals. The escape pattern of responding observed at these values has also been noted in previous studies using short R-UCS intervals during the same type of schedule with foot-shock with rats (Clark and Hull, 1966), and noise with humans (Azrin, 1958). Consequently, the escape response pattern may not derive from the present method but from the aversive schedule.

The principal advantage of this method is that it eliminates all unauthorized escape or avoidance reactions, thereby permitting precise specification of the duration and intensity of the shocks actually received, and also permits the use of very brief shock durations (100 msec in this study). Most theories of aversive control (Keller and Schoenfeld, 1950; Mowrer, 1939; Miller, 1948; Dinsmoor, 1954; Anger, 1963; Azrin and Holz, 1966) have emphasized the importance of specifying what responses, or stimuli, are present at the precise moment that the aversive stimulus is increased or terminated. The present method permits this exact specification of the response-shock or stimulus-shock relation.

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